Breakthroughs In Infrared Technology Using Semiconductor Quantum Dots

The FAST Center and the Air Force Research Laboratory

One of the goals of the FAST Center program is to provide students with exposure to Air Force research needs through ties with the Air Force Research Laboratory (AFRL). Because of the proximity of the University of New Mexico FAST Center to the directed energy directorate (AFRL/DE) and the space vehicles directorate (AFRL/VS) at Kirtland Air Force Base, these opportunities have flourished. In particular, FAST Center students have conducted research in AFRL laboratories using unique facilities for the characterization of infrared countermeasure materials. Former students have become researchers at AFRL developing advanced space-based sensors. Finally, AFRL scientists also leverage the unique facilities established at the FAST Center to grow and fabricate IR devices. By directly involving the students of today in Air Force research, the people and the technology the Air Force needs tomorrow will be ready.

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quantum dots. Semiconductor quantum dots confine electron motion in three dimensions, rather than in only one dimension as in a quantum well by embedding nanometer-sized islands of narrow bandgap semiconductor inside a different semiconductor with a larger bandgap. In this case indium arsenide (InAs) dots are embedded in gallium arsenide (GaAs).

These dots mimic the quantum mechanical behavior of isolated atoms with two important differences. First, because they are embedded in a semiconductor, it is easy to excite electrons bound to the quantum dots by simply passing current through the semiconductor. The second difference is that these dots are active in the infrared portion of the spectrum instead of in the visible or ultraviolet portion where isolated atoms show activity. Electrons in quantum dots have very well defined energy levels, similar to isolated atoms, in contrast to the range of energy levels found in quantum wells. As a result, light that is released when an electron makes a transition from a high energy level to a lower energy level in a quantum dot has a very sharply defined wavelength that can be tuned to the infrared by the size of the dot. This makes semiconductor quantum dots ideal candidates for discriminating between different targets with hyperspectral imaging.

During investigation of the possible use of semiconductor quantum dots for strategic sensors and detectors, an important insight was made into how to maintain the dot's activity as far into the infrared (IR) region as possible. The goal was to do everything possible to keep the indium concentration in the dot high to ensure IR activity. This insight was implemented by sandwiching the dots inside a separate indium-rich layer inside the GaAs semiconductor. This layer, called a quantum well, provided extra indium for the dot after its formation and made the dot active far into the IR.

Using this "dots-in-a-well" (DWELL) configuration, the UNM-AFRL team made two important discoveries. The first was lasers using DWELL configuration had the world's lowest threshold current density, which is a measure of how much current it takes to turn on the laser. The FAST Center team presently has the current density down to 16 amperes per square centimeter, a 68 percent reduction over the previous best. Previously, the record stood at 50 amperes per square centimeter in another type of semiconductor laser. This should translate directly to the efficiency of operation of infrared systems and reduce the supporting hardware weight and power by a similar percentage.

The second important discovery was that these quantum dot lasers behave very differently from other semiconductor lasers and perhaps not too surprisingly, behave like atomic lasers in some ways. This has very important consequences for the high power semiconductor lasers needed for infrared countermeasures. Previously, conventional semiconductor lasers have exhibited instabilities when highly excited to produce high power. This occurred because flooding the semiconductor with current changed the optical properties, causing the lasing characteristics to fluctuate. This phenomenon is described by the "alpha parameter," also called the linewidth enhancement factor. Typical values are around 3 with about 0.5 being the lowest ever reported.

ABOVE: From left to right: Guangtian Liu, Dr. Hua Li and Dr. Tim Newell study a quantum dot laser diode.